

# LWFA as a Preinjector for XFEL Driver Linac

Xiongwei Zhu

Institute of High Energy Physics, Chinese Academy  
of Sciences, P.O.Box 918, Beijing 100049, China

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## Abstract

In this paper, we propose to use the LWFA as the preinjector for XFEL driver linac. We can use LWFA to produce the femtosecond electron beam. The peak current of the produced beam can reach tens of  $kA$  and is high enough to drive XFEL so that the present bunch compressing technique can be deserted. The output optical pulse length can be as short as  $1fs$ .

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## 1 Introduction

LWFA is one of the candidates for the future accelerator[1, 2]. On the high energy frontier, people want to use LWFA technique to construct compact linear collider; On the high quality beam frontier, the researchers try to use LWFA as FEL driver. There are many kinds of conventional electron guns, such as high voltage DC electron gun, microwave electron gun. Plasma based electron gun is a new kind of electron gun. Free electron laser is the full coherent light source and needs high brightness electron injector. Low emittance and high peak current are the aim we pursue. The conventional gun has the limit. Up to now, the best achieved normalized emittance of the photoinjector is  $1mmrad$  with the bunch charge of  $1nC$ . If we need more bright electron bunch, we may use the new mechanism to produce the high quality electron beam.

Laser plasma based accelerator is a key research highlight in the field of new concept accelerator[3, 4, 5]. In the past, there are some proposals[6, 7, 8, 9] to use LWFA as the FEL driver linac directly. But it is difficult to get the stable high energy electron beam with the present LWFA experiment.

So, LWFA may be the potential electron linac preinjector. This new kind of electron gun has the advantages of the ultrashort bunch length, the ultra-low emittance, and the high peak current quasi-monoenergetic electron beam. It is unnecessary to use the bunch compressor to get the high peak current beam with our proposed electron preinjector.

## 2 Laser wakefield accelerator

Laser wakefield accelerator ( LWFA ) [2, 3, 4, 5] had a great breakthrough during the past 4-5 years. With the discovery of the bubble mechanism, the 1 GeV or so quasi-monoenergetic electron beam is obtained in the LWFA experiments [3, 4, 5]. The energy spread is still several percent and can not be used as the FEL driver. But this produced beam can be used as the high brightness electron injector due to their low normalized emittance, ultrashort bunch length, and high peak current. In this case, we just need tens of MeV high quality electron bunch to be used as the preinjector of the driver linac.

## 3 Application for next generation light source-Free Electron Laser

In [6], we propose a new mechanism LWFA to produce femtosecond electron bunch with the bunch length of  $2fs$ , and the peak current of  $750A$ . This kind of electron bunch can be used to produce ultrashort Terahertz coherent radiation. The peak current is also high enough to drive soft X-ray free electron laser, if we boost the beam energy to  $1GeV$  or so.

In this paper, as an example, we give the 2D PIC simulation [10] example result of one LWFA experiment design with the peak current in the range of  $15 - 20kA$ . The used code is Vorpal [10], Vorpal is an object-oriented PIC code developed by Tech-X Corporation. The typical laser parameters are the wavelength of  $800\text{ nm}$ , the pulse length of  $1.6\mu m$ , the beam waist of  $2.2\mu m$  and the peak intensity of  $1.63 \times 10^{20} W/cm^2$ . The typical plasma parameters are the plasma density of  $5.99 \times 10^{19}/cm^3$ . Table 1 gives the main parameters.

Table 1. Typical LWFA parameters

Laser	
Wavelength	$800nm$
Waist	$2.2\mu m$
Rep	$10Hz$
Peak Intensity	$1.63 \times 10^{20} W/cm^2$
Pulse length	$5.3fs$
Plasma	
Density	$5.99 \times 10^{25} m^{-3}$
Plasma wavelength	$4.32\mu m$
Output beam	
Energy	$37MeV$
Normalized emittance	$1.2\mu m$
Rep	$10Hz$
Energy spread	$3.9\%$
Bunch charge	$40pC$

Under these parameters, we can get the electron beam with the energy of  $37MeV$ , the bunch charge of  $\sim 40pC$ , the bunch length of  $\sim 1fs$ , the normalized emittance of  $1.2mmrad$ , and the rms energy spread of  $3.9\%$ . Figure 1 shows the output 2D density distribution of the produced electron beam.

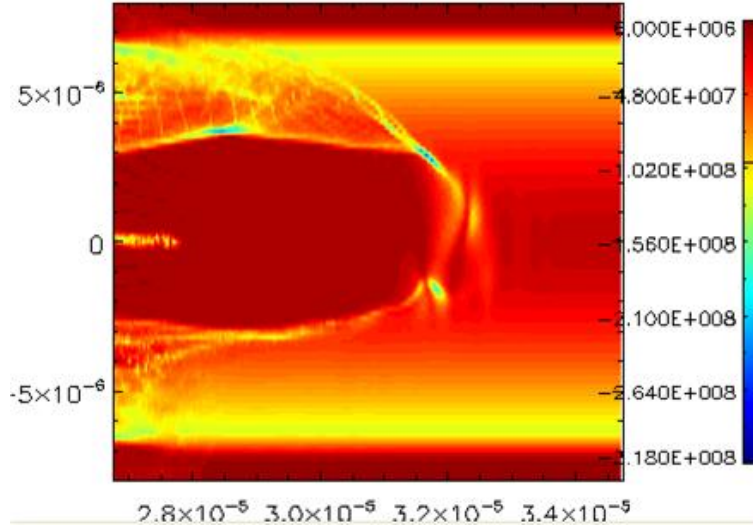


Figure 1. The 2D electron density (the colour stands for the density strength).

We analyze the phase space of the bunched beam in the bubble. Figure

2 shows the output beam phase space.

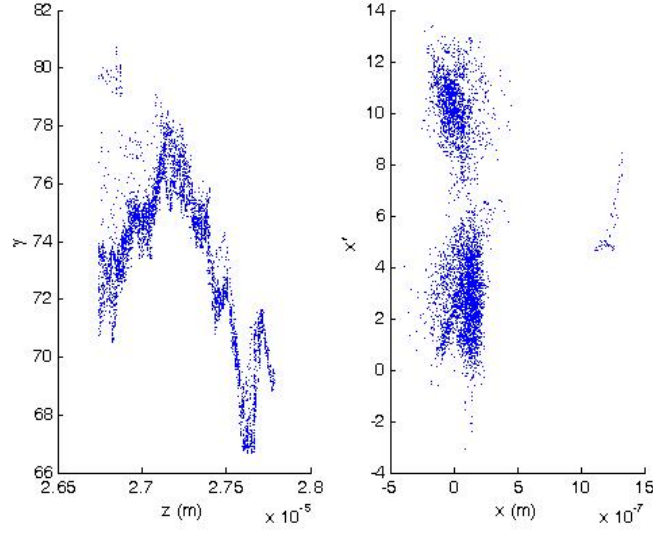


Figure 2. The longitudinal and transverse phase space.

Figure 3 shows the current profile, the peak current can reach  $15 - 20 \text{ kA}$ .

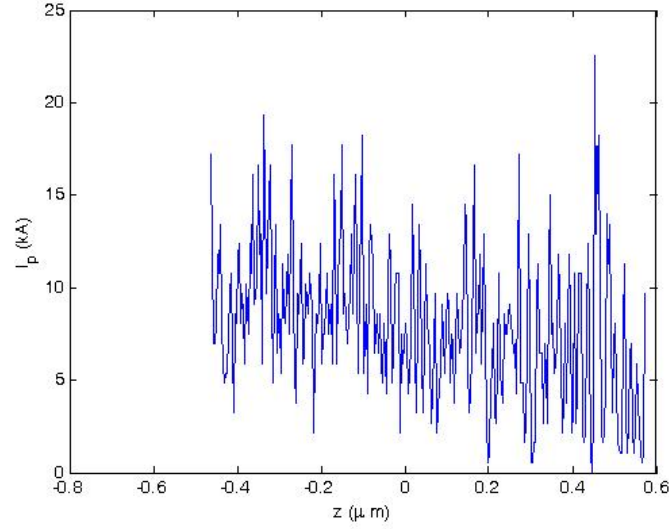


Figure 3. The current profile.

Then, we use this injector to set up soft x-ray free electron laser experiment. We add the booster linac after the lwfa injector to boost the beam

energy to the energy of 1 GeV. The linac can choose SLAC 2856MHz S-band accelerating structure or Spring-8 5712MHz accelerating structure. Due to the high peak current and femtosecond bunch length, we don't use the bunch compressor to obtain the high peak current bunch to drive XFEL process. We use the typical beam parameters: the energy of 1GeV, the normalized emittance of 1.2mmrad, the energy spread of 0.1%, and the peak current of 15 – 20kA.

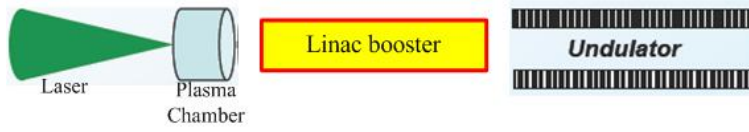


Figure 4. The schematic layout of XFEL experiment.

We use M.Xie's fitting formula[11] to estimate the SASE mode FEL output. Using the mature undulator parameters: the period of 3cm, and the gap of 1cm. The typical output parameters are the wavelength of 12.5nm, the peak output laser power of 90GW, the saturation length of 8m, and the gain length of 0.33m. The analytically estimated peak power is bigger than the simulated peak power ( $\sim 40GW$ ) by GENESIS. The main parameters are summarized in Table 2.

Table 2. Main parameters of the soft X-ray

Electron beam	
Energy	1GeV
Normalized emittance	1.2 $\mu m$
Rep	10Hz
Energy spread	0.1%
Bunch charge	40pC
Peak current	15 – 20kA
Undulator	
Period	3cm
Gap	1cm
K	
Saturation length	8m
Photon	
Wavelength	12.5nm
Peak power	40GW
Pulse length	1fs
Rep	10Hz

Using GENESIS[12] to do time independent and dependent simulation, the typical output peak power is shown as

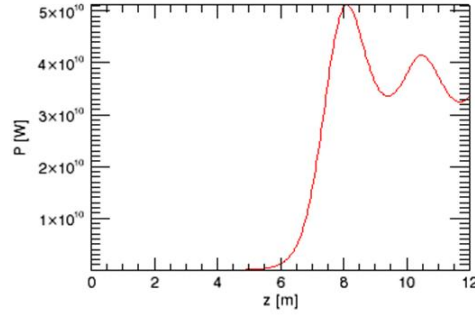


Figure 5. The output peak power along the distance.

the simulation shows the output peak power is about  $40GW$  which is smaller than the analytically estimated value, and the saturation length is about  $8m$ . Figure 6 shows the output laser spectrum.

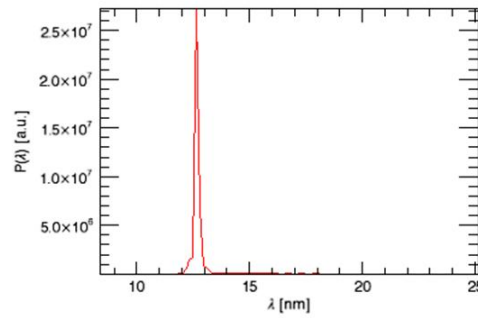


Figure 6. The output laser spectrum.

## 4 Discussion

In order to use LWFA as the electron injector, we have to solve some issues, such as the stability problem, the timing problem, etc. As we know, the conventional electron injector is more stable than LWFA. As the output electron bunch is in the order of femtosecond, the timing jitter will also be in this order. Therefore, the timing jitter problem maybe not a serious problem for our case.

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